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SEISMIC RESPONSE ANALYSIS OF BASE ISOLATED BUILDING: EFFECT OF LEAD RUBBER BEARING CHARACTERISTICS

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Abstract: Seismic response of a base isolated building is studied for varying properties of Lead rubber bearing. An eight storied educational building is taken into consideration as a structure of interest. Properties of the lead rubber bearing are altered to find the most optimum value of important parameters to obtain a minimum earthquake response of the building. The most important parameters are taken into consideration: initial stiffness (K_1), yield strength (F_y/W) and post-to-pre yield stiffness (K_2/K_1). Three different ground motions are considered in the present analysis and applied in the longitudinal direction of the structure. Base shear, roof acceleration and bearing displacement are utilized to evaluate the performance of the isolated building. It is found that these parameters influence the response of the building significantly and seismic response of the structure reaches to a minimum value for a specific value of the bearing parameter. Finally, some recommendations are made based on the present seismic analysis with different ground motions.

Keywords: *Seismic response, lead rubber bearing, initial stiffness, base shear and ground motion*

1.0 Introduction

Now-a-days base isolation technique is widely used in the structures as an earthquake resistive device in different countries of the world (Buckle and Mayes, 1990). The method has got popularity due to its cost effectiveness and impressive performance against earthquakes. In isolation technique, the frequency of the structure is shifted outside the dominant frequency of the ground motion (Kelly, 1986). As the structure decouples from the ground, force can't be transmitted and response reduces significantly. Mainly three different types of material are used to construct isolation system: Natural rubber bearing, Lead rubber bearing and High damping rubber bearing. It is found that the lead rubber bearing shows better performance than other two types of bearing (Haque *et al.*, 2010).

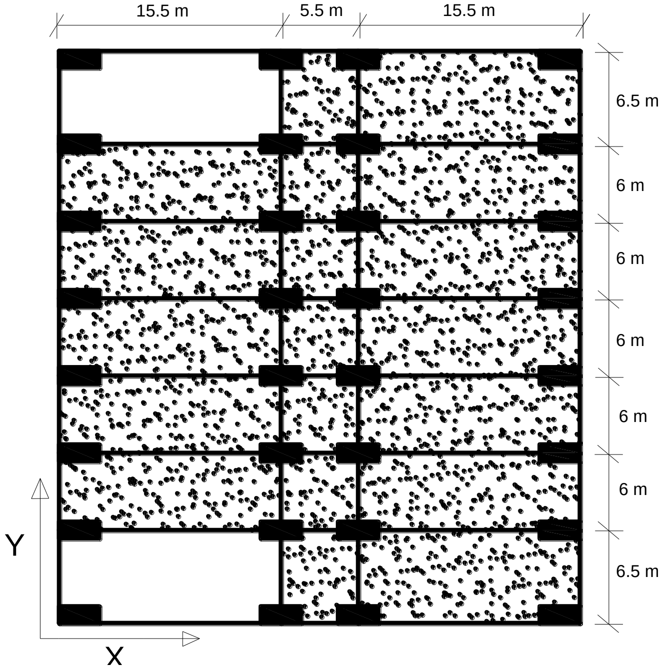
Several researches have already been done to establish the effectiveness of seismic isolation system over the last few decades (Oh and Kim, 1998; Kunde and Jangid, 2003). It is now important to improve the efficiency of the isolation system by investigating the effect of different modeling parameters of lead rubber bearing on the response of structure. Realizing the importance of aforesaid issue, Naeim and Kelly (1999) investigated post-to-pre yield stiffness (K_2/K_1) effect on the response of a structure and recommended a value of 0.1. Jangid (2006) performed series of simulations to investigate the effect of characteristics strength (Q_d/W) and recommended a range of values from 0.10 to 0.15. But from the literature review it is found that characteristics strength value depends on the post yield stiffness (K_2) value. So it is more logical to understand the yield strength (F_y/W) effect on response of structure rather than characteristics strength. Moreover, Jain and Thakkar (2000) simulated post-to-pre yield stiffness (K_2/K_1) effect by varying the value in between 0.05 to 0.25 but found no significant effect and requires further investigation to make clear the issue. Moreover, the sensitivity due to the types of ground motion is also required to consider as the response of the structure is highly sensitive to the type of ground motion (Haque *et al*., 2013; Bhuiyan *et al.*, 2012). Now taking all these issues into consideration, seismic response of a base isolated tall building is carried out for various bearing properties. Mainly the initial stiffness (K_1), yield strength (F_y/W) and post-to-pre yield stiffness (K_2/K_1) of the lead rubber bearing are taken into consideration. Three different ground motions are applied in the longitudinal direction of the building. Results are mainly discussed in terms of base shear, roof acceleration and bearing displacement. Finally some recommendations are made based on the obtained results.

2.0 Modeling of the Building

The building considered for the present analytical study is an eight storied educational building which is a reinforced concrete ordinary moment resisting frame structure. The dimension of the building is 36.5 x 43 m (X-Y) and total height of the building is 26 m. The building is symmetric in X axis but asymmetric in Y axis. The floor plan and elevation of the building is shown in Figure 1. Each floor consists of 150 mm thick concrete solid slab. There are total 32 numbers of columns in each level. To simplify the design of the building one type of section is used for all the column of the building. Details dimension of the structural components are given in Table1. Damping of the superstructure is assumed to be 5% of the critical damping in all modes. The building of the present case is modeled numerically by commercial structural analysis software SAP 2000 to obtain the seismic response. The building frame is modeled by 3-D beam column elements and the bearings are modeled by link element, which is characterized by bilinear model. The linear elastic model is considered to characterize the beam-column element. The floor at the each level is modeled by linear elastic shell element and assumed as rigid. The bottom of the building is considered to restrain in all directions. The analysis is based on following assumptions: The superstructure is elastic at all time and the non-linear behavior is restricted in the bearing only. The isolation bearings are rigid in the vertical direction and have negligible torsion resistance.

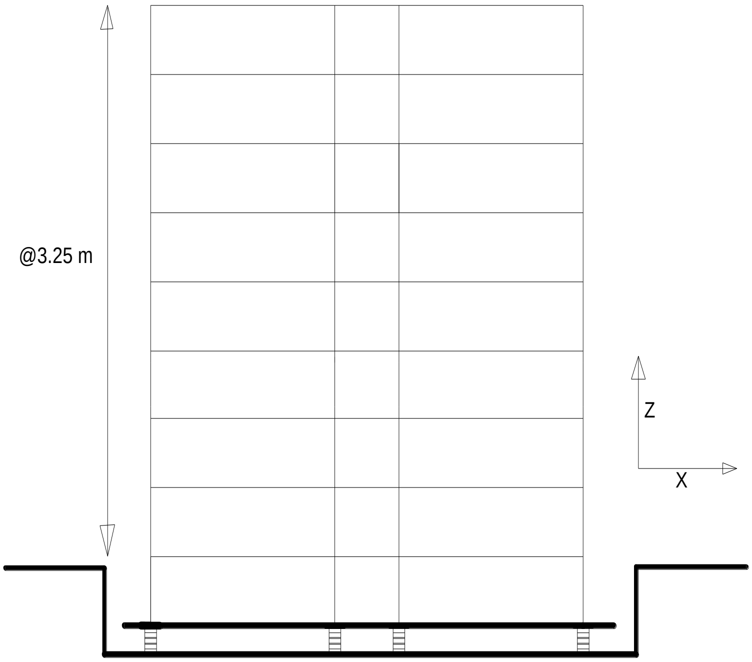
3.0 Modeling of the Bearings

As shown in the Figure 1(b) that the isolation is installed in between the building base slab and the foundation base slab. Under each of the column a rubber bearing is provided. To make the simulation simple the dimension and properties of the isolation is kept same for all the columns. The details of the isolation system are mentioned in the Table2. In this parametric investigation the Lead Rubber Bearing (LRB) used is shown in Figure 2(a). The elastomeric LRB is consists of two steel plates at the top and bottom of the device, with several alternating steel shims and central lead core. The purpose of the top and bottom plates is to compact the whole system, rubber will give lateral flexibility, steel shims will provide vertical load carrying capacity and central core will provide damping. When the structure with isolation system experiences earthquake, the rubber layers deform laterally by shear deformation, allowing the structure to translate laterally.



(a)

Figure 1: Typical plan (a) and elevation (b) of the buildings are considered in the study



(b)

Figure 1(cont'): Typical plan (a) and elevation (b) of the buildings are considered in the study

Table 1: Section properties of the structural components of the building

Properties	Specification
Cross-section of the Column (mm x mm)	500 x 300
Cross Section of the Beam (mm x mm)	300 x 400
Roof Thickness (mm)	150

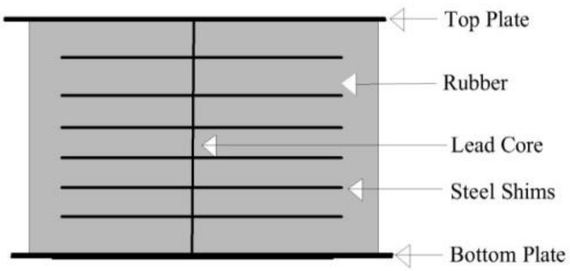
Table 2: Sectional properties of the isolation bearings

Dimension	Specifications
Length (mm)	650.0
Width (mm)	650.0
Height (mm)	168
Thickness of rubber layers (mm)	20
Thickness of Steel Layer (mm)	4
Number of Bearings	32

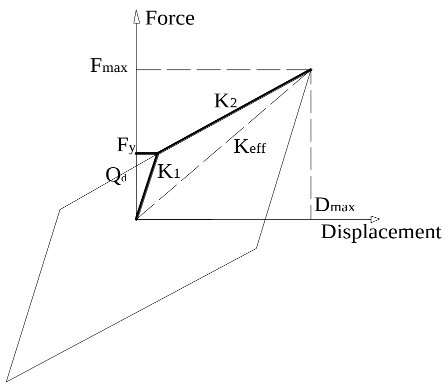
To describe the mechanical characteristics of the LRB bearing, the bilinear model describe in JRA (2002) is used as shown in Figure 2(b). Here, K_1 is elastic stiffness or initial stiffness, K_2 is post-yield stiffness, k_{eff} is effective stiffness, F_y is yield strength, Q_d is characteristics strength, F_{max} is maximum design force and D_{max} is maximum displacement. In the present study the effect of initial stiffness (K_1), yield strength (F_y/W) and post-to-pre yield stiffness (K_2/K_1) is investigated. Three different values of initial stiffness (k_1) are considered: 3500, 1750 and 875 kN/mm. For each of the initial stiffness (k_1), three different values of yield strength (F_y) is considered normalized with the weight of the supporting load (W). Under each value of initial stiffness (K_1) and yield strength (F_y/W), the post-to-pre yield stiffness (K_2/K_1) is varied from 0.05 to 0.25 by altering the post yield stiffness (k_2) value to clarify their influence on seismic response of building. So, total 45 isolation properties are utilized and simulations are performed. To simplify the notation of bearing properties, Table 3 represents the considered notations of the bearing properties.

4.0 Earthquake Ground Motions

The ground motion that is recorded is varied from one station to another station (Nove, 2007). The amplitude, intensity and the frequency content of the ground motion are influenced by various factors like, epicenter distance, local site conditions and earthquake magnitude. But this variation could generate huge difference in the response of the structure. One of the most important parameter that influences the structural response is the frequency content of the recorded ground motions. To incorporate the effect of frequency content three different historical earthquake records are used in this analysis.



(a)



(b)

Figure 2: LRB system (a) and bilinear force-deformation characteristics of LRB (b)

Table 3: LRB parameter and notations

Sl. No	Fy/W	Initial Stiffness (K_1)(kN/m)		
		3500	1750	875
1	0.1	P11	P21	P31
2	0.2	P12	P22	P32
3	0.4	P13	P23	P33

These earthquakes are Kobe earthquake (Kobe, 1995), Sylmer earthquake (San Fernando Valley, 1971) and Nigata earthquake (Nigata. 1964).Time domain plot of these ground motions are shown in Figure 3. These earthquake records are characteristically different from each other, especially, in terms of PGA values, peak ground velocity (PGV), duration and dominant frequency range of the earthquakes. All three earthquake records correspond to near field earthquakes. The power spectral density (PSD) and governing parameters of the earthquake ground motion records are presented in Figure 4 and Table 4 respectively. Form Table 4 as can be seen that the dominant frequency range is different for these three earthquakes. For the case of Sylmer, the peak frequency is low and it will govern the response of the tall building rather than the other two considered ground motions.

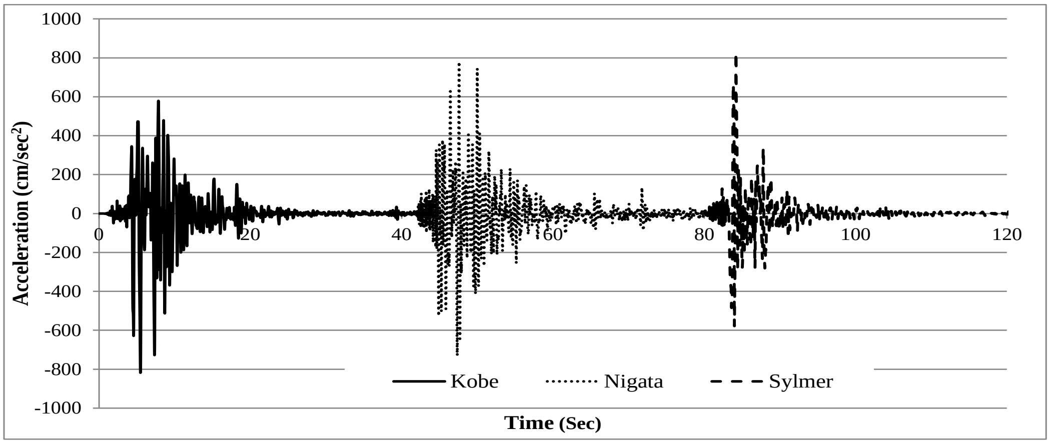
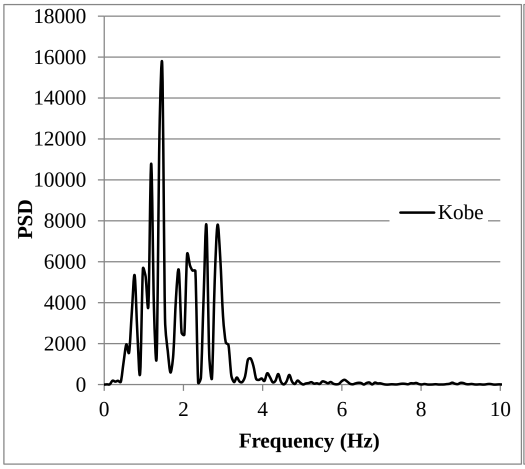


Figure3: Considered earthquake acceleration records for the analysis of the building



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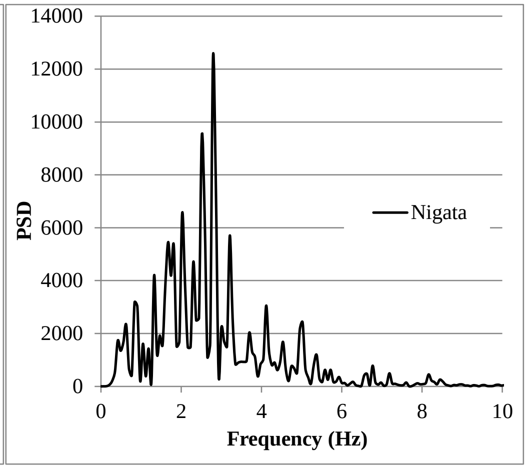

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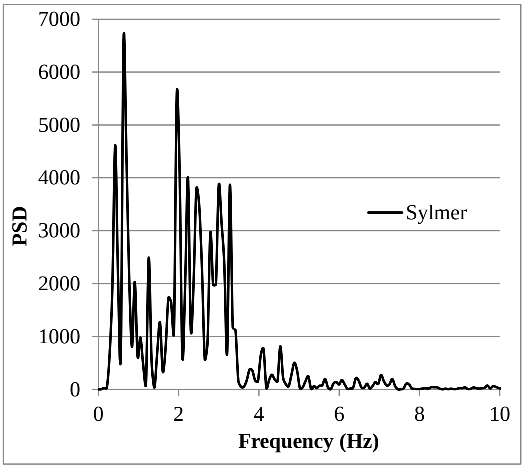


(c)

Figure 4: Fourier spectrum of Kobe (a), Nigata(b) and Sylmer (c) earthquake ground motion

Table 4: Important features of the earthquake records used in the analysis

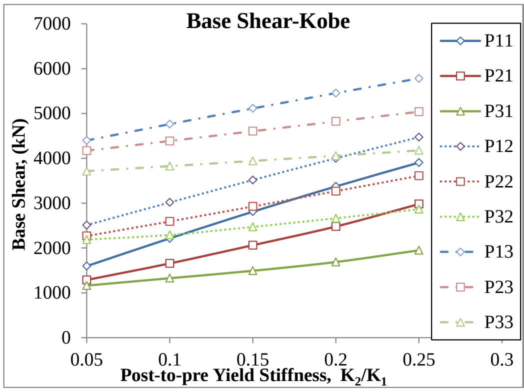
Name of the Earthquake	Maximum Acceleration (Gal)	Dominant Frequency (Hz)	Peak Frequency (Hz)
Kobe	+560.505 -817.825	1.0-3.0	1.46
Nigata	+779.244 -715.633	2.0-3.5	2.79
Shymler	+823.84 -578.034	0.4-3.8	0.628

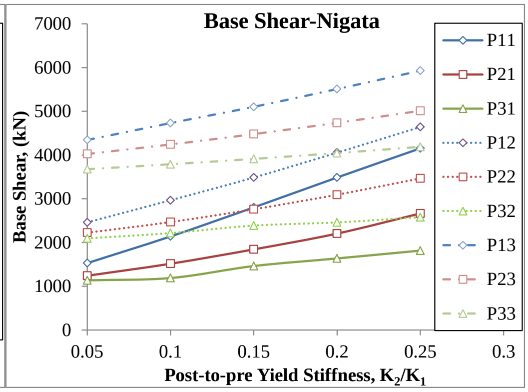
5.0 Results and Discussion

Seismic response of the building is carried out for three different ground motions as mentioned in section 4. Nonlinear dynamic analysis is performed with the isolation properties mentioned in Table 3. First, an Eigen value analysis is performed of the non-isolated building to reveal the modal characteristics of the building. The modal characteristics obtained from Eigen value analysis is presented in tabular format in Table 5. From Table 5, it is seen that the frequency of the first mode of vibration is 0.6 Hz with translation deformation, which is very close to the peak dominant frequency of the Sylmer ground motion. After getting the modal characteristics, analysis are run with isolation system with different properties. Results are mainly discussed in terms of base shear, roof acceleration and bearing displacement. Base shear for three different ground motions are presented in Figure 5. As can be seen from the figure that K_1, F_y/W and K_2/K_1 highly influences the response of the structure. For any values of yield strength (F_y/W) and initial stiffness (K_1), lower the value of post-to-pre yield stiffness ratio (K_2/K_1) lower the base shear of the building is. For a fixed value of yield strength (F_y/W) and post-to-pre yield ratio (K_2/K_1), higher the value of initial stiffness higher the response is. For a specific value of initial stiffness (K_1) and post-to-pre yield stiffness (K_2/K_1), if the yield strength (F_y/W) decreases the response of the structure also decreases. However, at lower value of post-to-pre yield stiffness (K_2/K_1), initial stiffness (K_1) doesn't have significant effect on response of structure. For the ground motion of Nigata, the peak frequency is too far from first mode of the vibration of the structure and can be seen that base shear becomes stable under P31for K_2/K_1 value of 0.1 to 0.05. While for earthquake Sylmer no such stable zone is found as the motion is strong. However, it is believed by the authors that further reduction of initial stiffens (K_1) or yield strength (F_y/W) may produce some stable value of base shear.

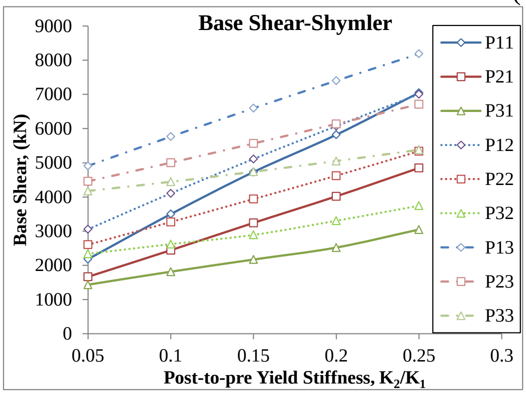
Table 5: Modal data of non-isolated building

Mode No.	Time Period (Sec)	Frequency (Hz)	Mode Characteristics
Mode -1	1.65591	0.60389	Translation
Mode -2	1.57602	0.63451	Translation
Mode -3	1.35647	0.73720	Rotation
Mode- 4	0.52133	1.91811	Bending
Mode -5	0.51969	1.92422	Bending





(a) (b)

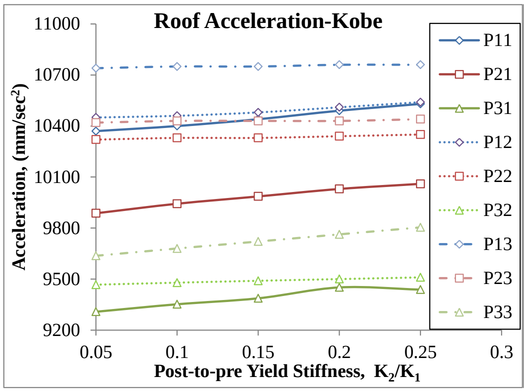


(c)

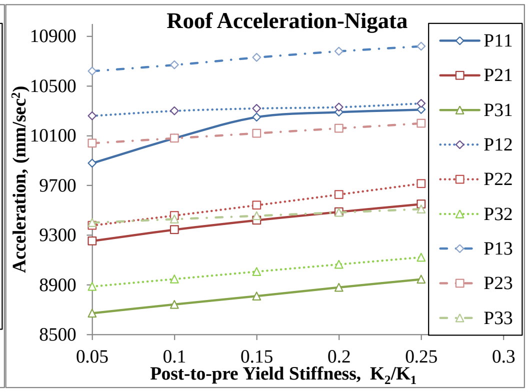
Figure 5: Base shear of isolated building with various isolation properties for Kobe (a), Nigata (b) and Sylmer (c) earthquake

Figure 6 shows the roof acceleration of the building under isolated condition. It also exhibits same behavior like base shear. At the lowest value of K_1, F_y/W and K_2/K_1, roof acceleration too has the lowest value. But there is no significant effect of K_2/K_1 on the roof acceleration response while yield strength (F_y/W) exceeds a value of 0.2.

Bearing displacement of the building is shown in Figure 7 for isolation properties shown in Table 3. It depicts the same trend like Figure 5 and Figure 6 but reverse order that is, at the highest value of K1, F_y/W and K_2/K_1, the displacement is highest. However, for the case of displacement, K_2/K_1 doesn't influence the displacement though it influences the base shear and roof acceleration significantly. At the higher value of initial stiffness (K_1), yield strength doesn't alter the displacement of structure, while at lower value of initial stiffness (K_1), yield strength increases the displacement. From serviceability point of view it is always required that during earthquake the structure will experience small displacement and it can be achieved by choosing larger value of initial stiffness (K_1) with smaller value of yield strength (F_y/W) and post-to-pre yield stiffness ratio (K_2/K_1).



(a)



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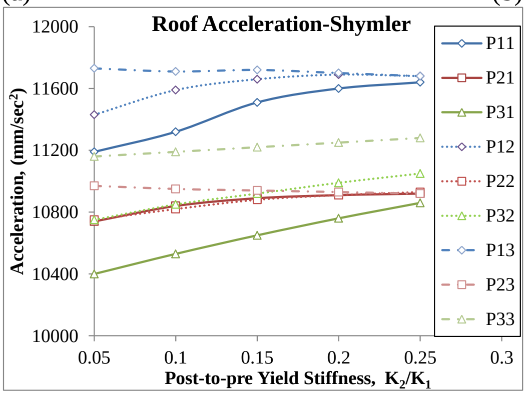

(c)

Figure 6: Roof acceleration of isolated building for various isolation properties under Kobe (a), Nigata (b) and Sylmer (c) earthquake

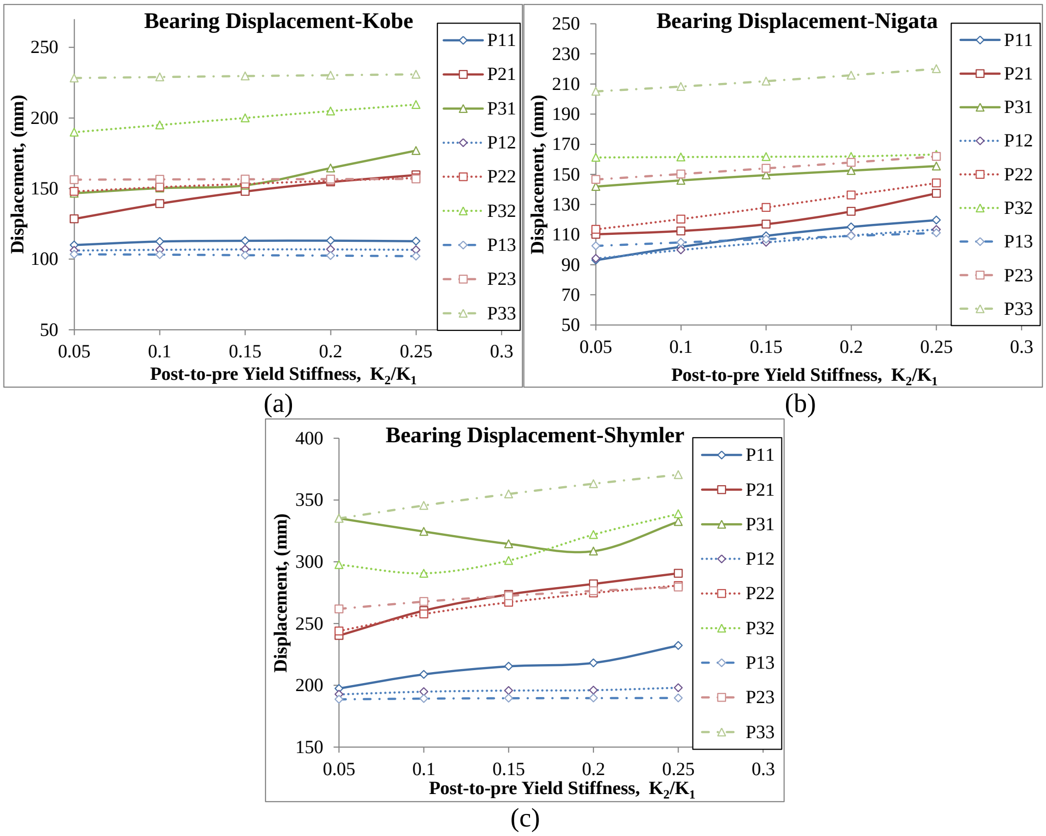

Figure 7: Bearing displacement of isolated building for various isolation properties under Kobe (a), Nigata (b) and Sylmer (c) earthquake

From Figure 5, 6 and 7 it can be seen that isolation properties of P31 with K_2/K_1 of 0.05 has the lowest base shear and roof acceleration but the displacement is too high, while the isolation properties of P11 with K_2/K_1 of 0.05, the base shear and roof acceleration is also small but the displacement is significantly lower than the former one. On the other hand, the isolation properties of P13 with K_2/K_1 of 0.25 have the highest base shear and roof acceleration with smallest displacement. So for practical use bearing properties of P11 would be the most preferable one. To compare the responses in between the non-isolated and isolated building with bearing properties of P13 and P31, the base shear and bearing displacement are plotted in Figure 8 and 9 respectively.

6.0 Conclusions

A parametric study on LRB properties is conducted for an eight storied building in this present work. Three important mechanical properties of isolation system are considered: initial stiffness (K_1), yield strength (F_y/W) and post-to-pre yield stiffness ratio (K_2/K_1). Simulations are conducted under three different earthquake ground motions and results are discussed in terms of base shear, roof acceleration and bearing displacement. The main outcomes of the research are mentioned below,

1) Performance of the isolation system can be improved significantly by selecting appropriate value of mechanical properties like, initial stiffness (K_1), yield strength (F_y/W) and post-to-pre yield stiffness ratio (K_2/K_1).

2) Yield strength (F_y/W) and post-to-pre yield stiffness (K_2/K_1) have governing effect to reduce the response of the structure like, base shear and roof acceleration over initial stiffness (K_1).

3) Higher value of initial stiffness (K_1) and lower value of yield strength (F_y/W) do not increase the displacement of the building but decreases the base shear and roof acceleration. Before designing isolation system a parametric study is required to obtain the appropriate value initial stiffness (K_1) for an efficient design.

4) Lower value of post-to-pre yield stiffness ratio (K_2/K_1) yields lower response without increasing the displacement of the building. A value of 0.05 to 0.1 is recommended for the design of isolation system.

5) The value of yield strength (F_y/W) should be less than 0.2 to obtain the advantage of smaller value of post-to-pre yield stiffness ratio (K_2/K_1), as at higher value of yield strength (F_y/W), pre-to-post yield stiffness ratio (K_2/K_1) doesn't reduce the response of the building.

Finally, the above mentioned guidelines can be used for designing an efficient Lead Rubber Bearing (LRB) isolation system.

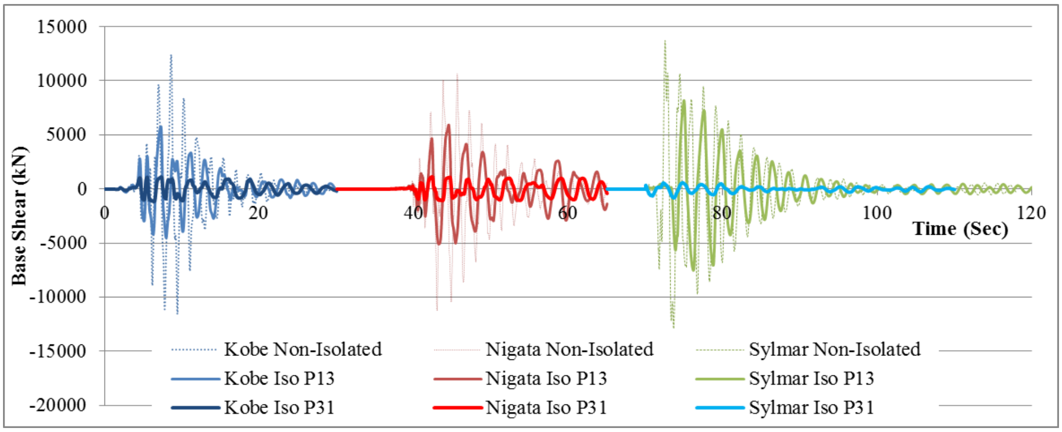

Figure 8: Base shear of non-isolated and isolated building

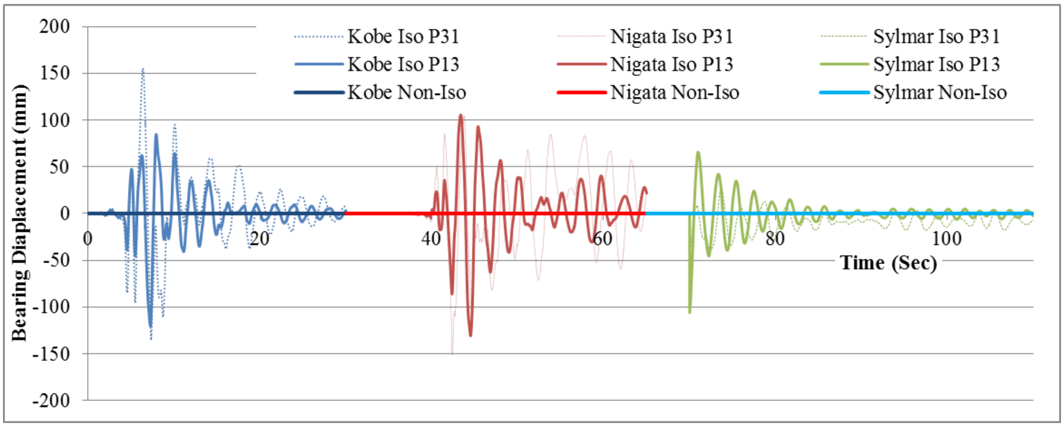

Figure 9: Bearing displacement of non-isolated and isolated building

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